

UNITED STATES AIR FORCE
RESEARCH LABORATORY

TESTING AND EVALUATION OF THE
THERAPEUTIC AND HIGH ALTITUDE
LOW OPENING (HALO) OXYGEN SYSTEM
FOLLOW-ON OPERATIONAL TEST
AND EVALUATION (FOT&E)
OF THE C-17 AIRCRAFT

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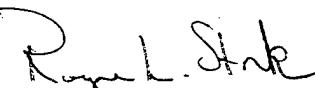
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**TESTING AND EVALUATION OF THE
THERAPEUTIC AND HIGH ALTITUDE
LOW OPENING (HALO) OXYGEN SYSTEM**

**FOLLOW-ON OPERATIONAL TEST AND EVALUATION
(FOT&E) OF THE C-17 AIRCRAFT**

SECTION 1

INTRODUCTION

1.0 PURPOSE AND BACKGROUND. HQ AMC/SG requested FOT&E to quantify the medical capabilities of the C-17 passenger oxygen system to support aeromedical (AE) operations. Specifically, this testing effort was performed to 1) determine if the therapeutic outlets could provide sufficient flow rates and pressures to support ventilators, 2) determine if the high altitude low opening (HALO) outlets could provide sufficient flow rates and pressures to support medical flow meters, and 3) document the effects of an emergency mask deployment on the HALO/ therapeutic function.

1.1 SYSTEM INFORMATION.

1.1.1 Background. Aeromedical oxygen system tests during dedicated Initial Operational Test and Evaluation (IOT&E) found that the therapeutic oxygen pressure was higher than the required 50 +/- 5 pounds per square inch gauge (psig). However, the test aircraft (89-1190, P-4) had not been modified with new oxygen regulators. Negotiated Change Order (NCO) 8375 addressed the modified HALO/therapeutic regulator, and thereafter modified regulators were installed on all production aircraft. This test intended to verify that the modified regulators meet aeromedical requirements. Additionally, HQ AMC/SG asked whether the HALO system could be used for therapeutic purposes, thereby increasing the number of available oxygen outlets for patient care. The impact of an emergency oxygen mask deployment on the therapeutic/HALO oxygen function was also questioned.

1.1.2 Description. The cargo compartment oxygen system consists of therapeutic, HALO, and emergency functions. The therapeutic function has five outlets to operate ventilators and respirators, while the HALO function has 58 outlets for personnel airdrop requirements. The emergency function provides emergency oxygen to all passenger and patient masks.

1.1.3 Test Team, Location, and Dates. This test was conducted on 29 June 1996 at Pope AFB, NC in conjunction with the C-17 Personnel Formation Airdrop Test. Armstrong Laboratory (AL/CFTS), Brooks AFB, TX provided a test engineer and two data collectors.

SECTION 2

FOT&E OUTLINE

2.0 CRITICAL OPERATIONAL ISSUES (COIs)

2.0.1 COI-1. Are solutions to previously identified deficiencies effective?

2.0.2 COI-2. Does the C-17 continue to effectively perform the air mobility mission?

2.1 SCOPE AND TEST CONCEPT

2.1.1 Test Scope. This test was to validate that the C-17 therapeutic oxygen system would meet aeromedical requirements during normal and emergency flight operations. It was also performed to evaluate the effectiveness of the HALO outlets to supplement the therapeutic system and thereby provide additional oxygen for aeromedical use. The test was conducted in three phases: 1) first we confirmed that the new oxygen regulator would meet established aeromedical operational requirements, 2) then we determined that HALO outlets could be used for medical purposes without degrading the therapeutic oxygen function, 3) and finally we assessed therapeutic/HALO oxygen function during simulated unpressurized flight conditions.

2.1.2 Test Concept. All tests (Supplement 4.0) were conducted on an instrumented, static aircraft. Armstrong Laboratory personnel instrumented the test aircraft with mass flowmeters, universal biometers, flowmeter switch boxes, and vacuum pumps. Armstrong Laboratory personnel used data collection sheets (Supplement 4.1) and photographs to document test results.

SECTION 3

METHODOLOGY

3.0 GENERAL

3.0.1 Description. The COI and supporting MOEs/MOPs for the therapeutic, HALO, and emergency oxygen functions were designed to assess the medical capabilities of the oxygen system. Specifically, this testing effort was performed to 1) determine if the therapeutic outlets could provide sufficient flow rates and pressures to support ventilators, 2) determine if the high altitude low opening (HALO) outlets could provide sufficient flow rates and pressures to support medical flow meters, and 3) document the effects of an emergency mask deployment on the HALO/ therapeutic function.

3.1 COI-1. Are solutions to previously identified deficiencies effective?

3.1.1 Scope. A static, instrumented aircraft was used to measure therapeutic oxygen pressures and flow rates.

3.1.2 Measures of Effectiveness/Performance (MOE/MOP) and Evaluation Criteria.

3.1.2.1 MOE 1-1. Whether there is sufficient oxygen pressure to operate ventilator(s) from therapeutic outlets. Criteria: Quantitative and Qualitative.

3.1.2.1.1 MOP 1-1-1. Measure oxygen system pressure with flow rate of 100 liters per minute (lpm) from one therapeutic outlet. Criteria: 50 +/- 5 pounds per square inch gauge (psig).

3.1.2.1.2 MOP 1-1-2. Flow rate from therapeutic oxygen system with outlet pressure below 45 psig. Criteria: None.

3.1.2.1.3 MOP 1-1-3. Measure oxygen system pressure with flow rate of 60 lpm from each of five therapeutic outlets. Criteria: > 40 psig.

3.1.3 Mission Scenarios. Ground testing was conducted on an instrumented aircraft as outlined below.

3.1.3.1 MOP 1-1-1. Test cadre opened the primary and auxiliary oxygen converter supply valves and the HALO/therapeutic regulators. Using a mass flowmeter and an adjustable oxygen valve, the flow rate from one therapeutic outlet was set to 100 lpm. The outlet pressure was then recorded.

3.1.3.2 MOP 1-1-2 and MOP 1-1-3. Test cadre opened the primary and auxiliary oxygen converter supply valves and the HALO/therapeutic regulators. Using mass flowmeters and adjustable oxygen valves, the flow rate from each of the five therapeutic outlets was set to 60 lpm. Outlet pressures were then recorded. As flow rates were being increased, the point that the outlet pressure dropped below 45 psig was noted.

3.1.4 Method of Evaluation. Test cadre documented pressures and flows on a data collection sheet.

3.1.5 Results. Test results show there is sufficient oxygen pressure to operate ventilator(s). Data from phase 1a (MOP1-1-1) showed that with a 100 lpm load on the therapeutic oxygen system, pressure was recorded at 49.5 psig, within the quantitative criteria of 50 ± 5 psig. Data from phase 1b testing (MOP 1-1-3) showed that with a 60 lpm load on all five therapeutic oxygen outlets, recorded outlet pressure was at 43.9 psig, which was within the specified criteria of > 40 psig. It was also noted that it took the system flowing at 249.1 lpm for the outlet pressure to fall below 45 psig. As an added measure for validation of effectiveness, the test cadre ran a qualitative test. Five ventilators, three Bear 33s and two Impact 750s, were connected to the therapeutic oxygen system. Each ventilator was set to simulate a normal breathing profile (850 ml tidal volume, 16 breaths per minute, and a 50 lpm peak flow). The test cadre operated these units in this configuration for 30 minutes and the monitored therapeutic outlet pressure never fell below 50 ± 5 psig. The previously identified deficiency during IOT&E was not demonstrated during C-17 FOT&E.

3.1.6 Recommendations. Acknowledge capability of the C-17 therapeutic oxygen system to operate up to five ventilators/respirators.

3.2 COI-2. Does the C-17 continue to effectively perform the air mobility mission?

3.2.1 Measures of Effectiveness/Performance (MOE/MOP) and Evaluation Criteria.

3.2.1.1 MOE 2-1. Whether there is sufficient oxygen pressure to operate medical flow meters from HALO outlets. Criteria: Quantitative.

3.2.1.1.1 MOP 2-1-1. Measure oxygen system pressure with simultaneous flow of 15 lpm from each of four therapeutic outlets, 20 lpm from one therapeutic outlet, and 6 lpm from each of five HALO outlets. Criteria: 50 +/- 5 psig.

3.2.1.1.2 MOP 2-1-2. Measure oxygen system pressure with simultaneous flow of 15 lpm from each of four therapeutic outlets, 20 lpm from one therapeutic outlet, and 15 lpm from each of five HALO outlets. Criteria: None

3.2.1.2 MOE 2-2. Whether there is sufficient oxygen pressure to sustain ventilators/respirators after an emergency mask deployment. Criteria: Quantitative.

3.2.1.2.1 MOP 2-2-1. Measure oxygen system pressure with simultaneous flow of 15 lpm from each of four therapeutic outlets, 20 lpm from one therapeutic outlet, 6 lpm from each of five HALO outlets and activation of 150 emergency oxygen masks. Criteria: 50 +/- 5 psig.

3.2.2 Mission Scenario. Testing was conducted on an instrumented aircraft as outlined below.

3.2.3 Method of Evaluation. Test cadre documented pressures and flows on a data collection sheet.

3.2.3.1 MOP 2-1-1 and MOP 2-1-2. Test cadre opened the primary and auxiliary oxygen converter supply valves and HALO / therapeutic regulators. Using mass flowmeters and adjustable oxygen valves, the flow rate on each of four therapeutic outlets were set to 15 lpm, the flow rate on one therapeutic outlet set to 20 lpm, and the flow rate on each of five HALO outlets to 6 lpm. Outlet pressures were then recorded. If any MOP pressure was outside its criteria range, the MOE was reported as deficient.

3.2.3.2 MOP 2-2-1. The test aircraft was configured with 12 litter stations, 48 centerline seats, and 54 sidewall seats. Test cadre opened primary and auxiliary oxygen converter supply valves and HALO/ therapeutic regulators. Using mass flowmeters and adjustable oxygen valves, flow rate on each of four therapeutic oxygen outlets was set to 15 lpm, the flow rate on one therapeutic outlet was set to 20 lpm, and the flow rate on each of five HALO outlets was set to 6 lpm. Outlet

3.2.3.3 pressures were recorded. Test cadre applied vacuum to the altitude test ports of two emergency oxygen regulators using suction pumps. Altitudes were simulated at FL250 and FL380. One hundred and fifty emergency oxygen masks were then deployed and activated. Outlet pressures were recorded and compared to criteria. If any MOP pressure was outside its range, the MOE was reported as deficient.

3.2.4 Results.

3.2.4.1 MOP 2-1-1 and MOP 2-1-2. There was sufficient oxygen pressure to operate up to five medical flowmeters from HALO outlets. With therapeutic and HALO outlets loaded, outlet pressure was recorded at 50.6 psig (6 lpm flow from each of five HALO outlets) and 50.1 psig (15 lpm flow from each of five HALO outlets), both within the criteria of 50 +/- 5 psig.

3.2.4.2 MOP 2-2-1. There was sufficient oxygen pressure to sustain ventilators/ respirators after emergency oxygen mask deployment. With 150 masks deployed and activated, outlet pressure was recorded at 51.4 psig (FL250) and 50.0 psig (FL380). Both of these values are within the specified criteria of 50 +/- 5 psig.

3.2.5 Recommendations. Acknowledge capability of HALO oxygen system to operate medical flowmeters from HALO outlets with a total load of 75 lpm flow.

SECTION 4

SUPPLEMENTS

4.0 ARMSTRONG LABORATORY TEST PLAN.

TP Control Number _____

TEST PLAN

C-17 THERAPEUTIC OXYGEN SYSTEM FOLLOW-ON AND EVALUATION
(FOT&E)

JON: TBD

7 January 1996

AEROMEDICAL RESEARCH
CREW TECHNOLOGY DIVISION
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SPONSORING AGENCY: (33rd Test Wing /MSgt Gary Jenkins)

TEST FACILITY: These tests will be accomplished using the Armstrong Laboratories Altitude Simulators, Brooks AFB, Texas and on site (Charleston AFB, SC).

TEST PERIOD: Last week of February 1996 or TBD.

1.0 **BACKGROUND:** In response to a request from the 33 FLTS and the C-17 Systems Program Office (SPO), AL/CFTS will instrument a C-17 aircraft and conduct testing so as to answer the MOE's/MOP's from AMC TEST 33-1-89/DPT 96-07 dated April 1996.

2.0 **TEST ARTICLE DESCRIPTION:**

The test article(s) will be the standard C-17 Therapeutic/ HALO and Emergency Oxygen System.

3.0 **SCOPE:**

This test plan provides the outline and guidance for measuring flows and pressures within the C-17 oxygen system.

4.0 **APPLICABLE DOCUMENTS:**

MIL-R-83178A

Regulators, Panel Mounted,
Oxygen, Diluter-Demand,
Automatic Pressure Breathing,

AIR STD 61/22
18 August 1982

Specification For The Minimum
Physiological Design Requirements
For Aircrew Breathing Systems

5.0 **TEST REQUIREMENTS:**

5.1 **GENERAL:** Specifications to be evaluated are described in the pass criteria section of each test.

5.2 TEST EQUIPMENT:

5.2.1 Pre-testing, Phase I, II, and III.

5.2.1.1 Variable Profile Breathing Simulator (VPBS)- The VPBS is a portable, microcomputer-controlled device which will reproduce pre-selected air-flow profiles that realistically simulate human respiration patterns.

5.2.1.1.1 Specifications:

Maximum Flow Rate	450 lpm
Breath Rate	2 to 50 BPM
Maximum Stroke (Tidal) Volume	6.75 liters
Profile (s)	Six, switch selectable
Temperature	32°F - 150°F
Profile Resolution	500 steps/profile cycle

5.2.1.2 Strip chart recorder- Mfg.: GOULD, Model: 2800 & Brush 200

5.2.1.2.1 Specifications: The individual plug-in module typically used for these tests is the universal amplifier.

Frequency Response	100 Hz
Channels	1-8
Chart Width	100mm/channel

5.2.1.3 Fleisch Pneumotachograph- Mfg: OEM Medical/ Whittaker Medical Manufacturing, Model: i/a 7319, Number 1

5.2.1.3.1 Specifications:

Model Number	For Deliveries	ID	Length	Dead Space	Weight
i/a	#1	60 lpm	18 mm	60 mm	15 ml

5.2.1.4 Variable reluctance differential pressure transducers: Mfg.: Validyne Engineering Corp., Model (s) DP45 (Flow), DP15 (Pressures), and P305 (Pressure)

5.2.1.4.1 Specifications:

Linearity	+/- 1/2% FS best straight line
Output	35 mV/V full scale nominal
Zero balance	Within 5mV/V
Temperature	-65°F to 250°F
Thermal Zero Shift	0.01% FS/°F Typical
Accuracy	+/- 0.25% for differential

5.2.1.5 Perkin-Elmer Medical Gas Analyzer- Model 1100

5.2.1.6 Filtered 0-5 v DC variable power supply (if valve/regulator is electronic).

5.2.1.7 High gain carrier demodulators used to provide transducer excitation, and to amplify and demodulate the output of the variable reluctance differential pressure transducers (#4 above). Mfg: Validyne Engineering Corp., Model (s): CD15 Basic Signal Conditioner and CD12 Transducer Indicator.

5.2.1.7.1 Specifications:

Input Sensitivity	0.9-75 mV/V
Diff Amp Input Z	120K Ohms to common, each input
Gain	+/- 0.005%/ $^{\circ}$ F
Zero	+/- 0.001%/ $^{\circ}$ F
Freq Response	Flat +/- 10% from DC to selected frequency of 0.1, 1, 10, 100 Hz or 1 kHz
Common Mode Rejection	100 db DC-120 Hz

5.2.1.8 Tylan Model FM362 Mass Flowmeters

5.2.1.8.1 Specifications:

Ranges:	0 to 30 slm 0 to 50 slm 0 to 100 slm 0 to 150 slm 0 to 300 slm
Indication:	Output 0-5 vdc linearity to mass flow rate
Accuracy:	+/- 2% of full scale
Linearity:	0.5% of full scale
Repeatability:	+/- 0.2% of full scale

5.2.1.9 Tylan Power Supplies Model PS14

5.2.1.9.1 Specifications:

Environmental:	0 to 40° C
Electrical:	
Output Ripple:	25 mv RMS Max
Output Voltages:	+5.000 +/- 0.050 vdc +15.0 +/- 0.6 vdc -15.0 +/- 0.6 vdc
Input Voltage	115 vac +/- 10%, 50-500 Hz

5.2.1.10 Bio-tek Instruments Universal Biometer Model DPM-III

5.2.1.10.1 Specifications:

Operate Temperature Range:	10 to 40°C
Linearity:	+/- 0.5%
Accuracy:	+/- 1% of reading (up to 15 psi) +/- 2% of reading (all other)
Repeatability:	0.15%

5.2.1.11 Permagage Pressure Guage ID A453155/A9862.

5.2.1.11.1 Specifications:

Accuracy:	- +/- 2.5 % Full Scale
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5.2.1.12 Labview Data Acquisition System: A microcomputer with multitasking capability, real time data acquisition and a high resolution graphic display. A/D board provides sixteen channels of analog to digital conversion at a rate of 500 samples per channel, two digital to analog channels, and eight digital input/output lines.

5.2.3 Test Hardware

5.2.3.1 All tests will require the following equipment:

<u>ITEM</u>	<u>Manufacturer</u>
Medical Flowmeters	Ohio Medical
Various Oxygen Connectors and hoses.	Procured locally
Flowmeter Switchbox and Cables	Manufactured by Base Fabrication Facility

5.3 TEST CONDITIONS:

5.3.1 Environmental: All tests shall be conducted at local ambient temperature and barometric pressure that shall be recorded at the time of the tests. This information shall be available for computation of test data, where required, to normal temperature and pressure (NTP) conditions. NTP conditions shall be 29.92 inches of mercury and 70 °F.

5.3.2 Test Setup: As required for each phase of testing.

5.3.3 Tests to be Performed:

5.3.3.1 Phase 1a and 1b

5.3.3.1.1 Compare data to requirements as stated in section 3.7.1.7.8.3 of the C-17 Air Vehicle Specification (two tests) and demonstrate acceptable oxygen system operation.

Test Objective: Per paragraph 3.7.1.7.8.3 Aeromedical Oxygen MDC S002 (I) C dated 1 August 90: a) Verify that the therapeutic oxygen system has the flow rate capability of 100 lpm from any one of the therapeutic outlets while maintaining an internal operating pressure of 50 ± 5 psig at all outlets. b) Verify that the therapeutic oxygen system has the flow rate capability of at least 60 lpm per outlet from all five of the therapeutic outlets simultaneously while maintaining an internal pressure of at least 40 psig at all outlets.

Test Procedure:

- (a) Perform at ground level.
- (b) Verify both primary and auxiliary Passenger/Troop oxygen converter supply valves are open.
- (c) Verify both therapeutic and HALO regulators are open and one therapeutic outlet is flowing.
- (d) Using Tylan and adjustable oxygen valve, set flow rate to 100 lpm from therapeutic outlet #1.
- (e) Record therapeutic/HALO regulator outlet pressure at therapeutic outlets #1, 3 and 5 as well as at HALO outlets #3 and 4. **[Phase 1a]**.
- (f) Slowly increase flow rate from therapeutic outlet #1 until therapeutic/HALO regulator outlet pressure drops below 45 psig. Record flow rate.
- (g) Open all five therapeutic outlets. Using Tylan flowmeters and adjustable oxygen valves, set flow rate to 60 lpm at each outlet.
- (h) Record therapeutic/HALO regulator outlet pressure at therapeutic outlets #1, 3 and 5 as well as at HALO outlets #3 and 4. **[Phase 1b]**.

Pass Criteria: For (e) (phase 1a) above-Regulator outlet pressure stays within 50 +/- 5 psig. For (h) (phase 1b) above- Regulator outlet pressure stays above 40 psig.

5.3.3.2 Phase 2a and 2b

5.3.3.2.1 Demonstrate acceptable Aeromedical oxygen system operation using demand profiles outlined by HQ AMC/SGXR (Maj Gonsalves).

Test Objective: Demonstrate acceptable Aeromedical oxygen system operation during demand profiles outlined by HQ AMC/SGXR (Maj Gonsalves). These profiles simulate system requirements necessary to support a maximum configuration Aeromedical Mission.

Test Description: The therapeutic/HALO system will be loaded in the following configuration:

- (a) Four therapeutic outlets at 15 lpm.
- (b) One therapeutic outlet at 20 lpm.
- (c) Five HALO outlets at 6 lpm.

Test Procedure:

- (a) Perform at ground level.
- (b) Verify both primary and auxiliary Passenger/Troop oxygen converter supply valves are open.
- (c) Verify both therapeutic and HALO regulators are open and 5 therapeutic outlets and 5 HALO outlets are flowing.
- (d) Using Tylan flowmeters, set flow rate to 15 lpm from 4 of the therapeutic outlets, 20 lpm from the last therapeutic outlet, and 6 lpm from 5 of the HALO outlets.
- (e) Record therapeutic/HALO regulator outlet pressure at therapeutic outlets #1, 3 and 5 as well as at HALO outlets #3 and 4. **[Phase 2a]**.
- (f) Slowly increase flow rate from the 5 HALO outlets (which had been previously set to 6 lpm in step (d) above) to 15 lpm and record therapeutic/HALO regulator outlet pressure at therapeutic outlets #1, 3 and 5 as well as at HALO outlets #3 and 4. **[Phase 2b]**.

Pass Criteria: (phase 2a and 2b) Regulator outlet pressure stays within 50 +/- 5 psig.

5.3.3.3 Phase 2c1, Phase 2c2, and Phase 2c3

5.3.3.3.1 Demonstrate acceptable Aeromedical oxygen system operation using demand profiles outlined by HQ AMC/SGXR (Maj Gonsalves).

Test objective: Demonstrate acceptable Aeromedical oxygen system operation using demand profiles outlined by HQ AMC/SGXR (Maj Gonsalves). In addition to the regulator loading profiles outlined in Phase 2a and 2b (section 5.3.3.2.1), the litter, center line, and sidewall masks (total of 150 masks) will be deployed and activated placing an additional demand on the oxygen system. Our objective, during this phase of testing, will be to determine and measure to what affect this additional loading has on the therapeutic/

HALO oxygen system. This loading will be accomplished and effects measured while at ground level, simulated altitude of 25K ft and at a simulated altitude of 38K ft.

Test description: The therapeutic/HALO system will be loaded in the following configuration:

- (a) Four therapeutic outlets at 15 lpm.
- (b) One therapeutic outlet at 20 lpm.
- (c) Five HALO outlets at six lpm.

Test Procedure:

- (a) Perform at ground level. **[Phase 2c1]**
- (b) Verify both primary and auxiliary Passenger/Troop oxygen converter supply valves are open.
- (c) Verify both therapeutic and HALO regulators are open and 5 therapeutic outlets and 5 HALO outlets are flowing.
- (d) Using Tylan flowmeters, set flow rate to 15 lpm from four of the therapeutic outlets, 20 lpm from the last therapeutic outlet, and 6 lpm from 5 of the HALO outlets.
- (e) Insert Permagage calibrated pressure meter in place of C-17 system pressure meter.
- (e) Record internal system pressure and therapeutic/HALO regulator outlet pressure from the pressure meter in (e) above as well as therapeutic outlet #1 and HALO outlets #3 and 4.
- (f) Deploy and activate the litter, centerline, and sidewall masks (total of 150 masks).
- (g) Again record internal system pressure and therapeutic/HALO regulator outlet pressure from the pressure meter in (e) above as well as therapeutic outlet #1 and HALO outlets #3 and 4.
- (h) Insert suction machine output connector into the emergency regulators altitude test port and adjust to 282.4 mmHg (25 K ft) **[Phase 2c2]**.
- (i) Record internal system pressure and therapeutic/HALO regulator outlet pressure from the pressure meter in (e) above as well as therapeutic outlet #1 and HALO outlets #3 and 4.

(j) Adjust suction machine output to read 155.4 mmHg (38 K ft). [Phase 2c3].

(k) Record internal system pressure and therapeutic/HALO regulator outlet pressure from the pressure meter in (e) above as well as therapeutic outlet #1 and HALO outlets #3 and 4.

Pass Criteria: (Phase 2c1, 2c2, and 2c3) Regulator outlet pressure stays within 50 +/- 5 psig.

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